RECENT ELECTRON BEAM OPTIMIZATION AT PITZ

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Abstract

High brightness electron sources for linac based free-electron lasers operating at short wavelength such as FLASH and the European XFEL are characterized and optimized at the Photo Injector Test Facility at DESY, Zeuthen site (PITZ). In the last few years PITZ mainly was used to condition RF guns for their later operation at FLASH and the European XFEL. Only limited time could be spent for beam characterization. However, recently we have performed emittance measurements and optimization for a reduced gun accelerating gradient which is similar to the usual operation conditions at FLASH. The results of these measurements are presented in this paper.

INTRODUCTION

The Photo Injector Test facility at DESY, Zeuthen site (PITZ) is developing, characterizing and optimizing high brightness electron sources for free-electron lasers like FLASH [1] and the European XFEL [2]. One of the most important parameters, influencing the FEL process, is the normalized transverse projected emittance, hereinafter called emittance, of the electron beam. A normal conducting 1.6-cell L-band RF gun cavity with a Cs_2Te photocathode, which is illuminated by cylindrically shaped UV laser pulses, is used to produce high quality electron beams of different charges. The produced electron beam is focused with a pair of solenoids installed around the gun and accelerated further by the cut disc structure booster, hereinafter called CDS booster, after which numerous diagnostic devices are installed. The emittance of the electron beam is measured using the conventional slit scan method based on a direct measurement of the electron beam size and angular spread [3]. As the energy of the electron beam after the final acceleration is not sufficient to prevent a space-charge induced emittance growth, several emittance measurement stations are installed along the beamline to monitor the emittance evolution. More details about the PITZ setup can be found elsewhere [3–5]. All the data presented in this work were obtained using the first emittance measurement station installed just downstream the CDS booster.

In the last few years PITZ was mainly focused on conditioning of electron guns required by FLASH and the European XFEL without the possibility to perform comprehensive electron beam characterization and optimization due to the tight time schedule. However, recently we got the possibility to partially perform electron beam characterization with an RF gun which was conditioned at PITZ and will be delivered for further usage at the European XFEL. Due to lack of time, the measurements were performed only for 1 nC and 100 pC electron beam charges. Only emittance dependencies on the most sensitive machine parameters were measured. In the following section, measured data compared to the results of numerical simulations using the ASTRA code [6] are presented.

EMITTANCE SIMULATIONS AND MEASUREMENT RESULTS

Emittance dependencies on the main solenoid current, gun launching phase and rms laser spot size on the cathode were measured for electron beams with 100 pC and 1 nC charges. A flat-top temporal UV laser profile with a FWHM of about 21 ps was used and is presented together with the transverse laser profile in Fig. 1. The gun on-axis peak field on the cathode was reduced to about 53 MV/m, as compared to the nominal 60 MV/m which is planned for the European XFEL, in order to combine the electron beam characterization with gun stability tests at long RF pulses. This yields an accordingly reduced electron beam momentum after the gun of about $p_z \sim 5.9$ MeV/c as compared to about $p_z \sim 6.8$ MeV/c at 60 MV/m. Further acceleration by the CDS booster operated at the maximum allowed accelerating gradient and tuned to the maximum mean momentum gain phase, hereinafter called MMMG phase, resulted in a final electron beam momentum of about $p_z \sim 21.2$ MeV/c. The emittance of the electron beam was measured using the first emittance measurement station installed 5.74 m from the cathode [3]. For both probed electron bunch charges emittance dependencies on the main solenoid current were measured for various rms laser spot sizes on the cathode and an MMMG gun launching phase (an optimum gun phase according to the simulations, see e.g. [3, 4]). Additionally, for the electron beam with 1 nC bunch charge, the emittance dependence on the gun launching phase was measured for the rms laser spot size on the cathode delivering the minimum emittance at the MMMG phase.

Emittance Data for 1 nC Electron Bunch Charge

As it was mentioned, emittance dependencies on the rms laser spot size on the cathode and gun launching phase were measured for electron beams with a bunch charge of 1 nC.

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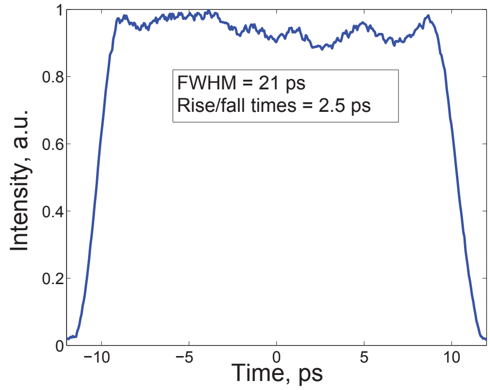
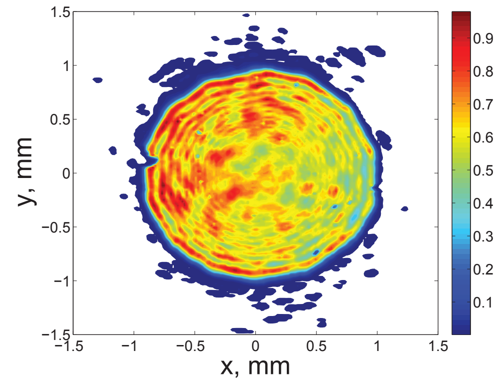
ISBN 978-3-95450-133-5



(a) Temporal profile.



(b) Transverse profile. $\sigma_{xy} = 0.48$ mm.

Figure 1: Examples of UV laser profiles used for emittance measurements. The temporal profile was tried to be kept constant for measurements with different electron bunch charges while the transverse spot size was varied.

For each laser spot size, a solenoid scan was performed in order to find the minimum emittance value. For the main solenoid current value delivering the minimum emittance, several statistical emittance measurements were done. The result of these measurements is presented in Fig. 2 and yield a minimum emittance value of $1.01 \pm 0.01\ \mu$m for an rms laser spot size at the cathode of 0.38 mm. Corresponding simulations were performed and yield a minimum emittance value of 0.77 μm for an rms laser spot size on the cathode of 0.45 mm. The measurement and simulation curves do not include data points for the rms laser spot sizes of less than 0.38 and 0.43 mm, respectively, since the 1 nC bunch charge could not be extracted anymore due to space-charge limitations at the cathode. As compared to the nominal gun on-axis peak field of 60 MV/m the obtained emittance values are higher by 26 % and 42 % in the simulations and measurements, respectively [3,4]. The difference between

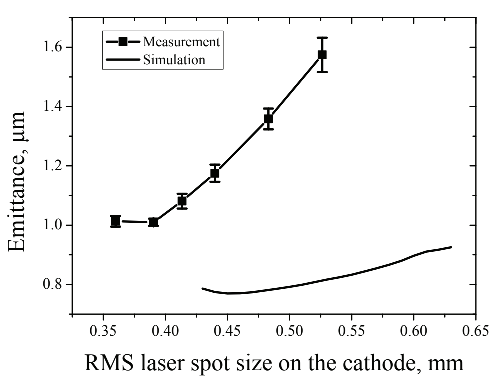


Figure 2: Emittance dependence on the rms laser spot size on the cathode for an electron beam with 1 nC bunch charge.

this measurement and earlier experimental results is larger than the difference between the corresponding simulations. The reason for this might be, that due to the tight schedule, not all machine parameters have been fully optimized. The strong discrepancy between the machine parameters delivering the minimum emittance in the simulations and measurements can be caused by Schottky-like effects which were not taken into account in the simulations [3]. An additional cause of the discrepancy is the deviation of the laser profiles which were used for the measurements from the ideal profiles used in simulations. As one can see in Fig. 1, there is a significant deviation of the transverse laser profile from the ideal uniform profile used in the simulations, caused by interference effects. The temporal laser shape is also not perfectly flat.

The emittance dependence on the gun launching phase was measured for a fixed laser spot size on the cathode. The rms laser spot size of 0.38 mm, which gives the smallest emittance (see Fig. 2) for the MMMG phase, was chosen. Like in the previous case, emittance solenoid scans were performed for each gun launching phase. For the solenoid current providing the minimum emittance value, several statistical emittance measurements were performed additionally. The result of these measurements is presented in Fig. 3. Emittance decrease for the gun launching phases of 6 and 9 deg during the measurements is not yet fully understood. It might be connected to the higher electric fields on the cathode during emission which yield accordingly enhanced Schottky-like effects which are not included in the simulations, as well as to the general limitations of the photoemission model used in the simulations at the conditions close to the space-charge limit [4]. Besides the above discussed parameters like the laser spot size, main solenoid current and the gun launching phase, the emittance is also influenced by the electron beam transport through the beamline. As shown in [3], there is a significant influence of the electron beam transport through the CDS booster on the emittance. Optimization of the transport through the CDS booster can be done based on direct emittance measurements. Magnetic fields of several steerer magnets upstream the CDS booster were varied in order to change the inclination and offset of the electron beam. The measured emittance as a function of steerers settings is presented in Fig. 4. As one can see, an improper electron beam transport has a significant influence

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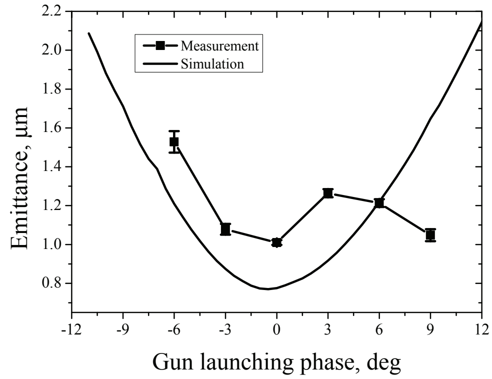

Figure 3: Emittance dependence on the gun launching phase, with respect to the MMMG phase, for an electron beam with 1 nC bunch charge.

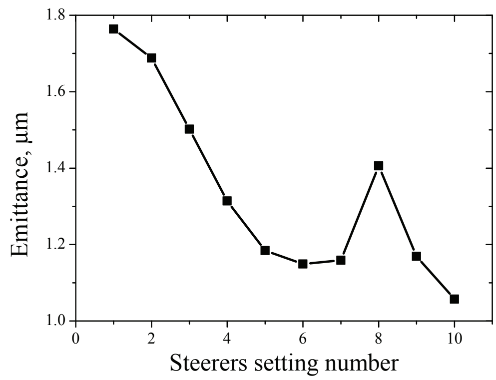

Figure 4: Emittance as a function of the steerer settings upstream the CDS booster.

on its quality due to consequent inhomogeneous acceleration of the electron beam in the CDS booster.

Emittance Data for 100 pC Electron Beam Charge

Due to lack of time, only the emittance dependence on the rms laser spot size was measured for electron beams with 100 pC charge. During these measurements the gun launching phase was fixed to the MMMG phase. As for previous measurements with 1 nC electron bunch charge, the main solenoid current scan was performed for each rms laser spot size on the cathode. For the main solenoid current delivering the minimum emittance, several statistical emittance measurements were performed. The result is presented in Fig. 5. A minimum emittance value of 0.26 ± 0.01 μm was found for an rms laser spot size on the cathode of 0.16 mm during the measurements. In the simulations a minimum emittance value of 0.18 μm was found for an rms laser spot size on the cathode of 0.17 mm. Similar to the measurements with 1 nC electron beams, there is a significant discrepancy between the emittance values obtained in measurements and simulations. As in 1 nC case it might be partially explained by Schottky-like effects, imperfections of the real laser profiles and by possible systematic errors during the emittance measurements which are not taken into account. For a previous similar measurement but at a peak field of 60 MV/m at the cathode, the systematic emittance overestimation was estimated to be at the level of about 10 % [3]. For a reduced field of 53 MV/m one can expect a larger emittance overestimation due to a stronger sensitivity of the emittance on machine parameters.

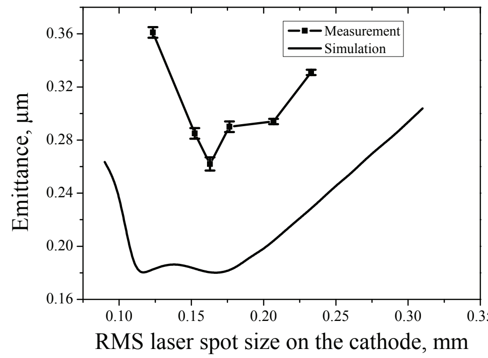

Figure 5: Emittance dependence on the rms laser spot size on the cathode for an electron beam with 100 pC bunch charge.

SUMMARY

After a long period devoted mainly to the conditioning of photo electron guns for their future usage at FLASH and the European XFEL, PITZ finally got the possibility to characterize the quality of the electron beam in terms of its emittance. The measurements with bunch charges of 1 nC and 100 pC were performed for the gun on-axis peak field at the cathode of 53 MV/m. Although this fun peak field is smaller than 60 MV/m foreseen for the European XFEL and the experimental beam optimization has been incomplete due to lack of time, the obtained emittance value of 1.01 ± 0.01 μm for an electron beam of 1 nC bunch charge is only 10 % higher than the required 0.9 μm for the European XFEL. Therefore one can expect that by bringing the gun to the nominal European XFEL operating gradient the emittance is expected to improve accordingly below the design value of 0.9 μm.

ACKNOWLEDGMENT

The authors would like to thank S. Schreiber for his valuable comments and careful proof-reading of this paper.

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ISBN 978-3-95450-133-5